Semi-annual Progress Report

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3. Subject of Investigation:

"Relative Roles of Gravitational and Inertial Work in the Energy Cost and Character of Human Locomotion"

4. Period of Investigation:

July 1, 1964, through June 30, 1966

5. Progress Report, January 1-June 30, 1965:

In our original research grant application for the period starting July 1, 1964, it was stated that two years would be necessary for completion of the planned research. The first year was to be spent in investigating the relation between gravitational work and energy expenditure in locomotion, and the second year in studying the effects of load and costume on the energy cost of walking under varying conditions of gravitational work.

Our semi-annual progress report dated January 1, 1965, described incomplete studies, comprising about 90 experiments, in which the relation between gravitational work and energy expenditure was investigated. Figs. 1-4 in the present report summarize further detailed studies, made up to April 1, 1965, on a normal young male subject walking at three different speeds on a variety of slopes.

At moderate speeds, 73.2 and 97.6 meters/min and at various slopes, the energy expenditure per minute appears to be dependent only on the vertical lift/step multiplied by the number of steps/min (bottom two lines in Fig. 4). At a low speed (48.8 meters/min, step rate 65/min), however, the walk became clumsy and ungainly for this tall subject. The relatively high energy expenditure for a given vertical lift at this speed, as compared with that at more normal gaits (top line of Fig. 4 compared with bottom lines) reflects the abnormal character of the gait. This is a most interesting result of our study, and leads to the second major research investigation contemplated for FY 1966, namely, the effects of load and costume on the energy cost of locomotion.

In connection with the above study, an analysis as outlined in the paragraphs below and in Figs. 5-8 is a part of the present investigation.

The total energy of the trunk, E_t, is the sum of potential energy, P.E., and kinetic energy, K.E. P.E. is calculated on the basis of the height of the center of mass of the trunk; K.E., from the measured speeds of the center of mass in the horizontal and vertical directions.

As in previous work, a vertical string attached near the center of mass passes through a transducer, which yields a continuous record of the instantaneous vertical displacement Z. Similarly, a horizontal string and another transducer yield a record of X, the instantaneous horizontal displacement.

Fig. 5 shows a 1.2-sec segment of the record. The top curve gives the value of Z; the middle curve gives X. The lowest curve represents the record obtained with use of an accelerometer attached to the right toe. From this curve it is possible to obtain the times of heel contact and of toe-off. The vertical time lines indicate intervals of 0.01 sec.

Instantaneous values of the slope of the X curve yield the values of $dX/dt = v_X$, which is the instantaneous value of the speed relative to a point moving with the treadmill. Addition of $\bar{V}_X$, the constant speed of the treadmill, yields V_X, the variable horizontal component of the speed of the center of mass.

In a similar way, curve Z yields the instantaneous values of Z, $dZ/dt = v_Z$, and V_Z.

Fig. 6 shows the values of X, Z, v_X, and v_Z for a time interval spanning step 4. The (intersecting) top two curves show values of X and Z, respectively. The maxima and minima are labeled MX, MZ, mX, and mZ, respectively.

The pair of intersecting curves in the lower part of Fig. 6 show the instantaneous speeds v_X and v_Z. The meaning of the prefixes M and m is the same as in the upper part of the figure.

The upper part of Fig. 7 shows the instantaneous excess over, or deficiency under, the K.E. associated with a constant speed of 162.8 cm/sec.

The P.E. curve in the lower part of Fig. 7 shows the potential energy in ergs/gm. The plotted magnitude includes an arbitrary constant, the value of which depends upon the choice of zero potential level (e.g., the floor of the treadmill, the lowest position of the center of mass, the mean position of the center of mass).

The E_t curve in Fig. 7 shows the total energy (sum of K.E. and P.E. and of a second arbitrary constant).

The upper part of Fig. 8 shows four superimposed single-step K.E. curves. The heavy curve is a "mean" K.E. curve.

Similarly, the lower part of Fig. 8 shows superimposed single-step and "mean" curves of P.E. and of E_t.

Examination of curve E_t, starting from 0.315 sec, shows the following energy-flow characteristics of a single step at 97.6 meters/min, at a slope of +3 degrees.

Soon after heel contact there is a loss of energy amounting to 4.85 cal (for a subject weighing 70 kg). Eventually, there is a gain of 11.7 cal, with a net permanent gain of 6.85 cal/step for a 70-kg subject.

We are now in the midst of a theoretical analysis of records of this type for speeds varying from 48.8 to 97.6 meters/min and for slopes varying from -3 to +3 degrees.

SLOPE WALKING ON THE TREADMILL

The effects of varied amounts of gravitational work on the energy cost of walking.

Normal young adult male, walking at speeds of 48.8, 73.2 and 97.6 meters/minute, and at slopes of −4° to +4°.

FIG. 1. 48.8 METERS/MINUTE

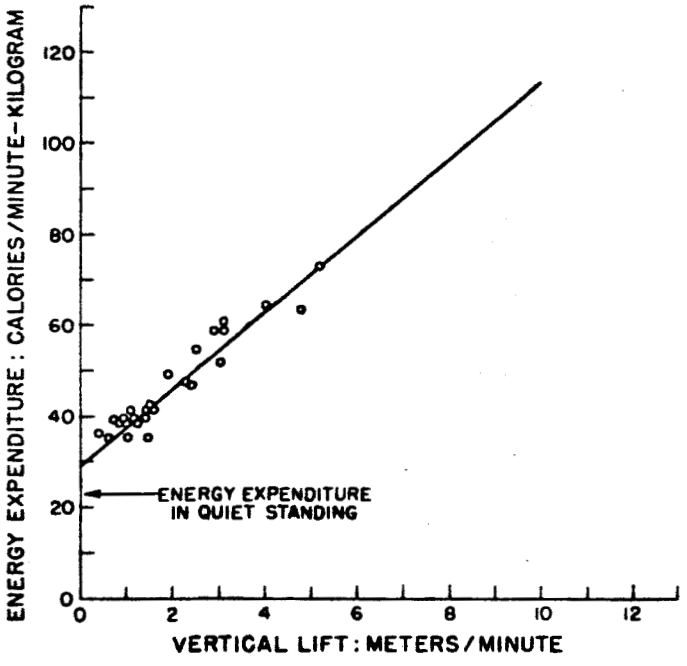


FIG. 2. 73.2 METERS/MINUTE

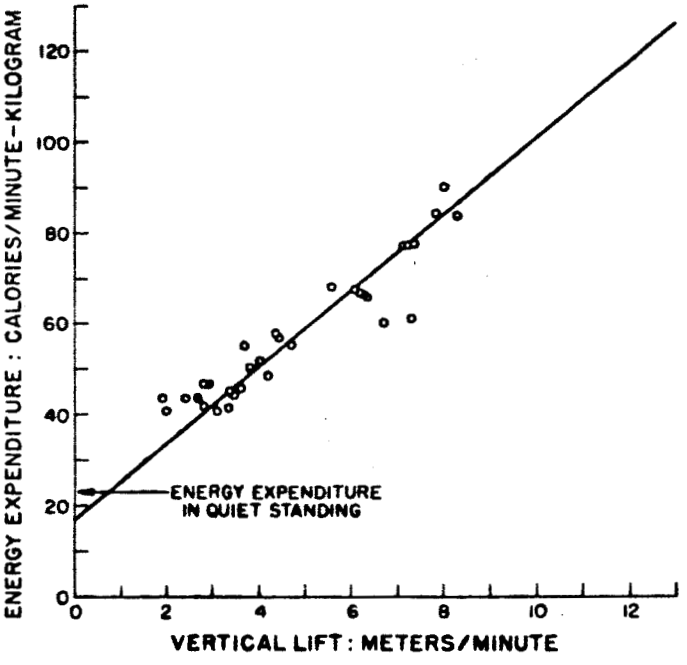


FIG. 3. 97.6 METERS/MINUTE

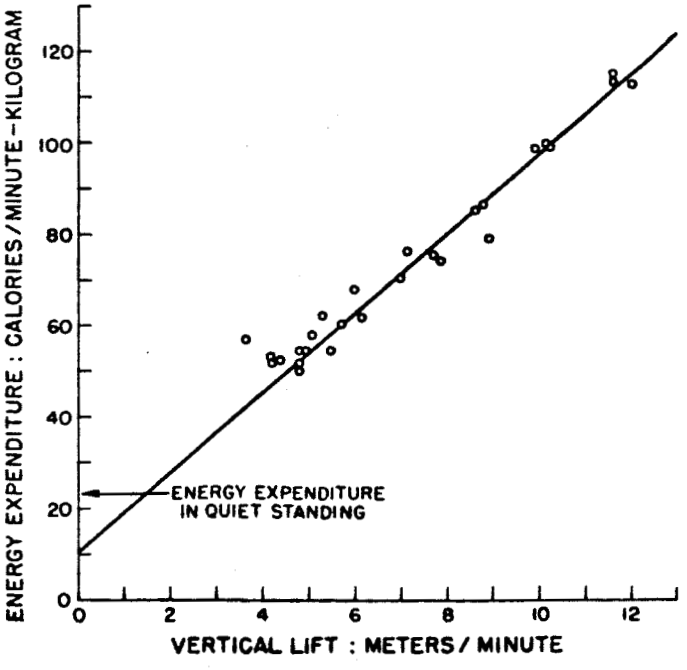
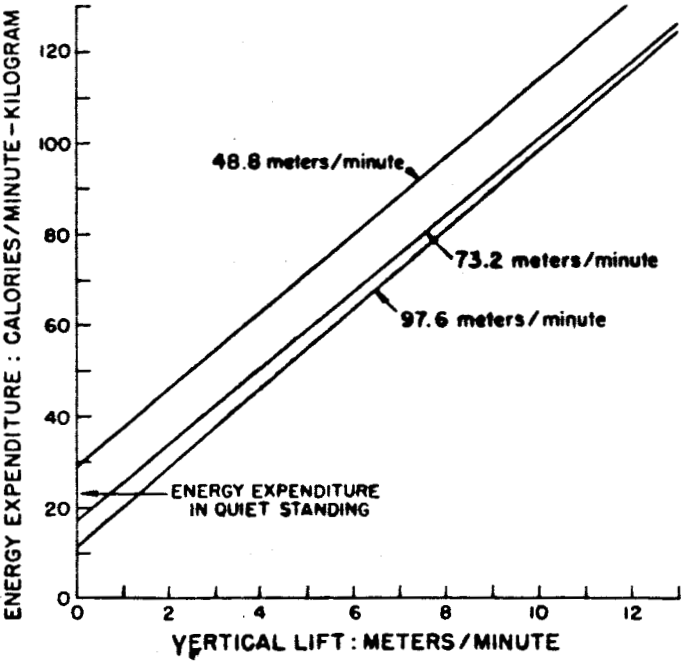


FIG. 4. SUMMARY OF FIGURES 1−3



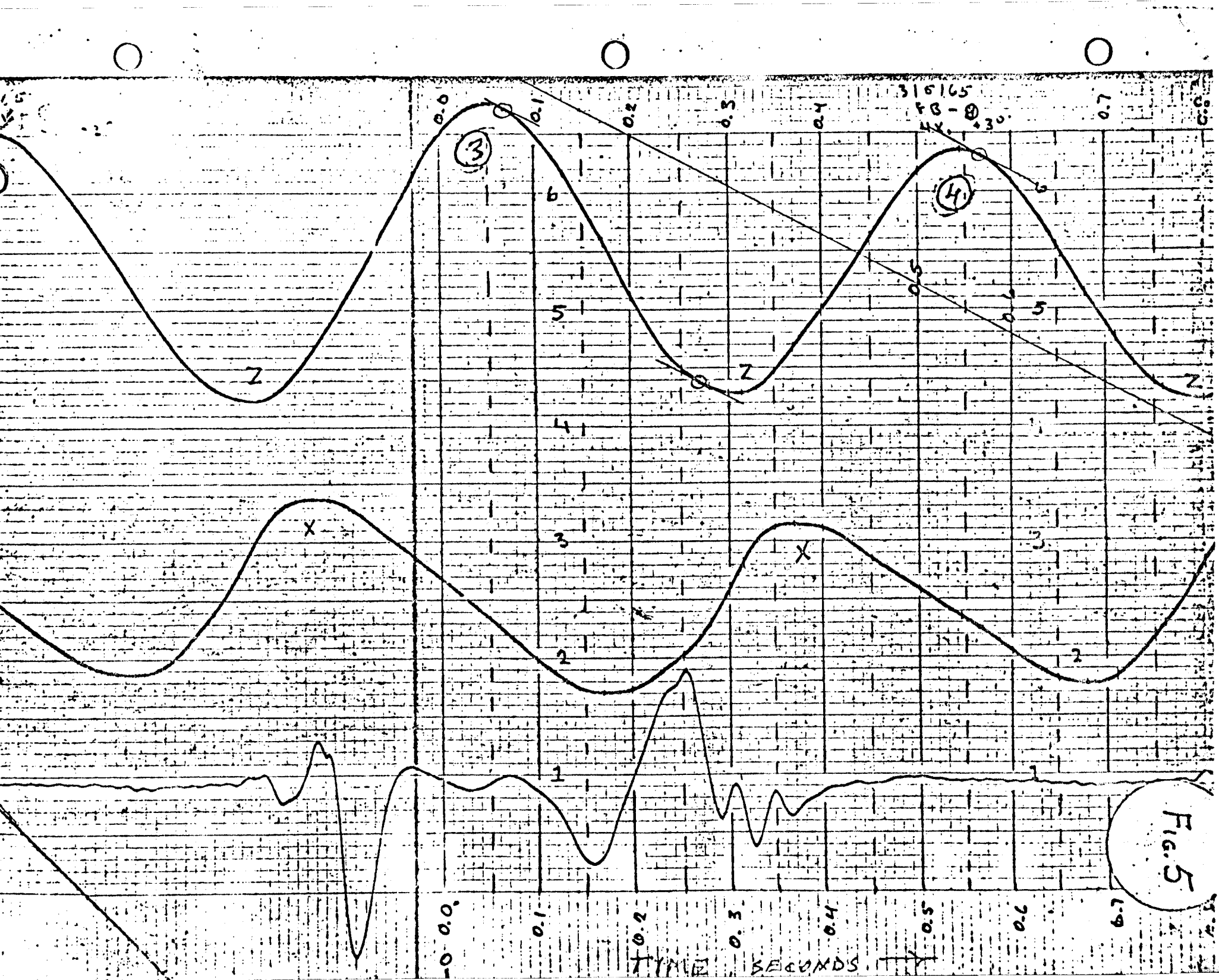


Fig. 5

3/5/65; Exp. 8; 4x; +3°; AJR

Fig. 6

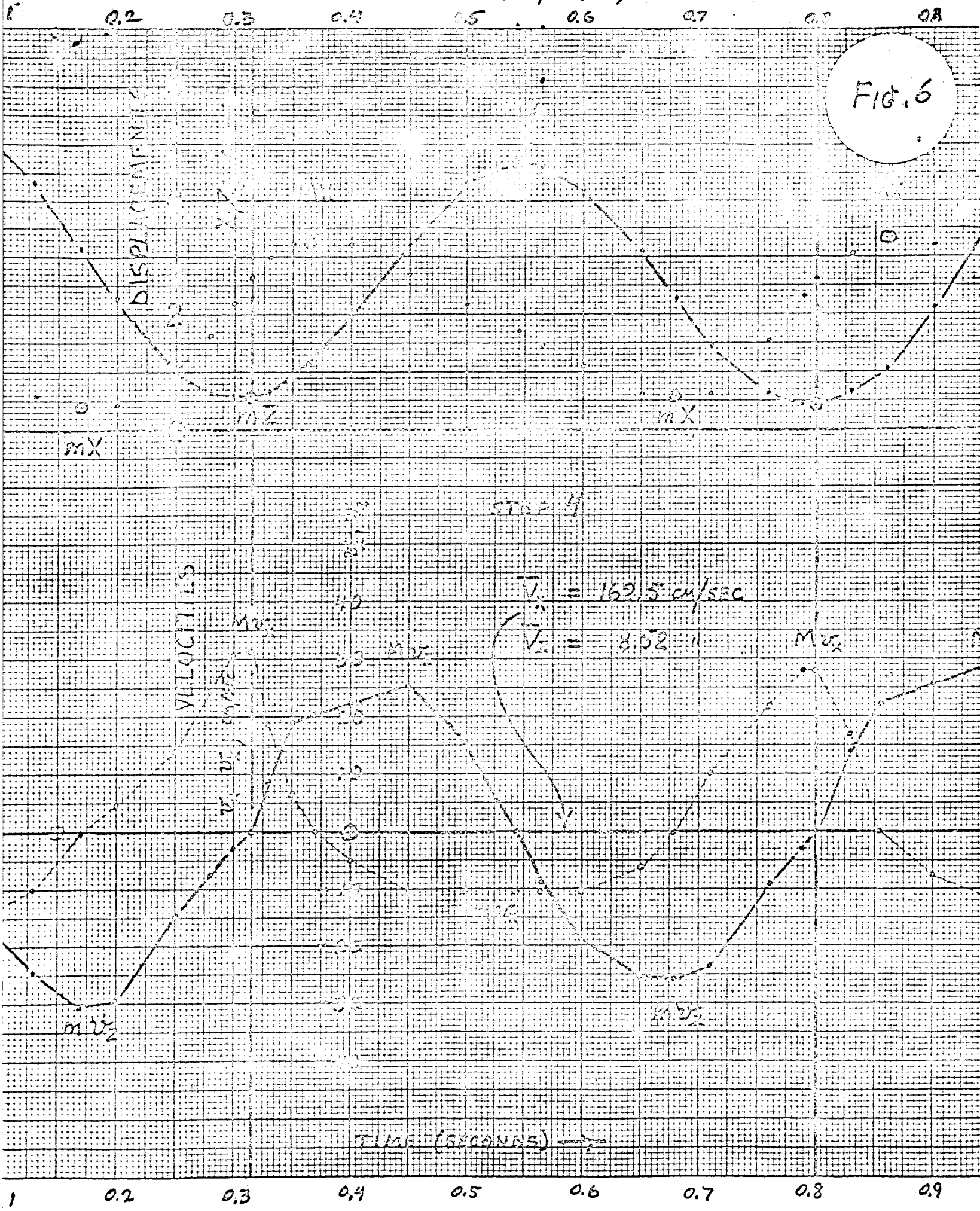
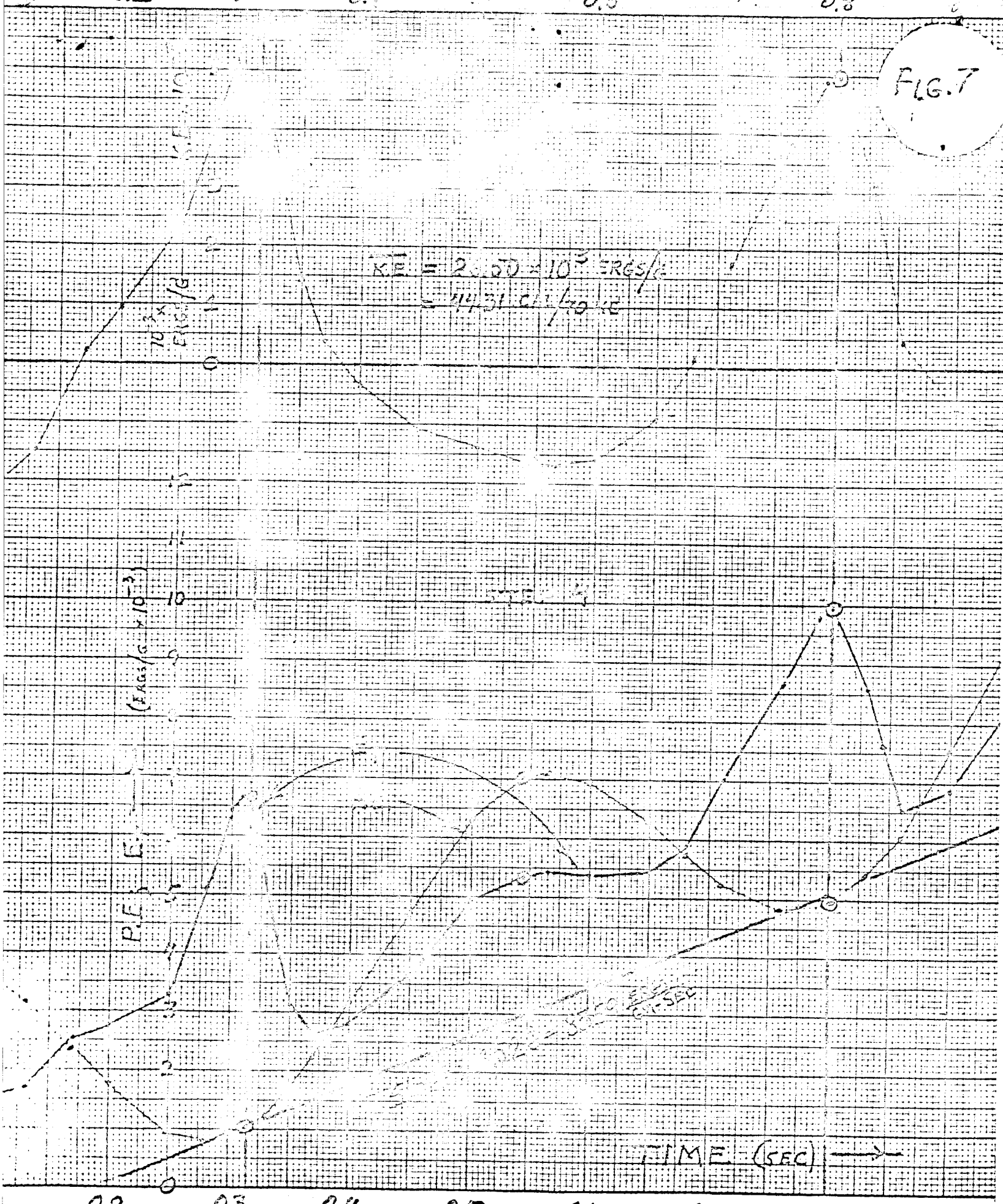
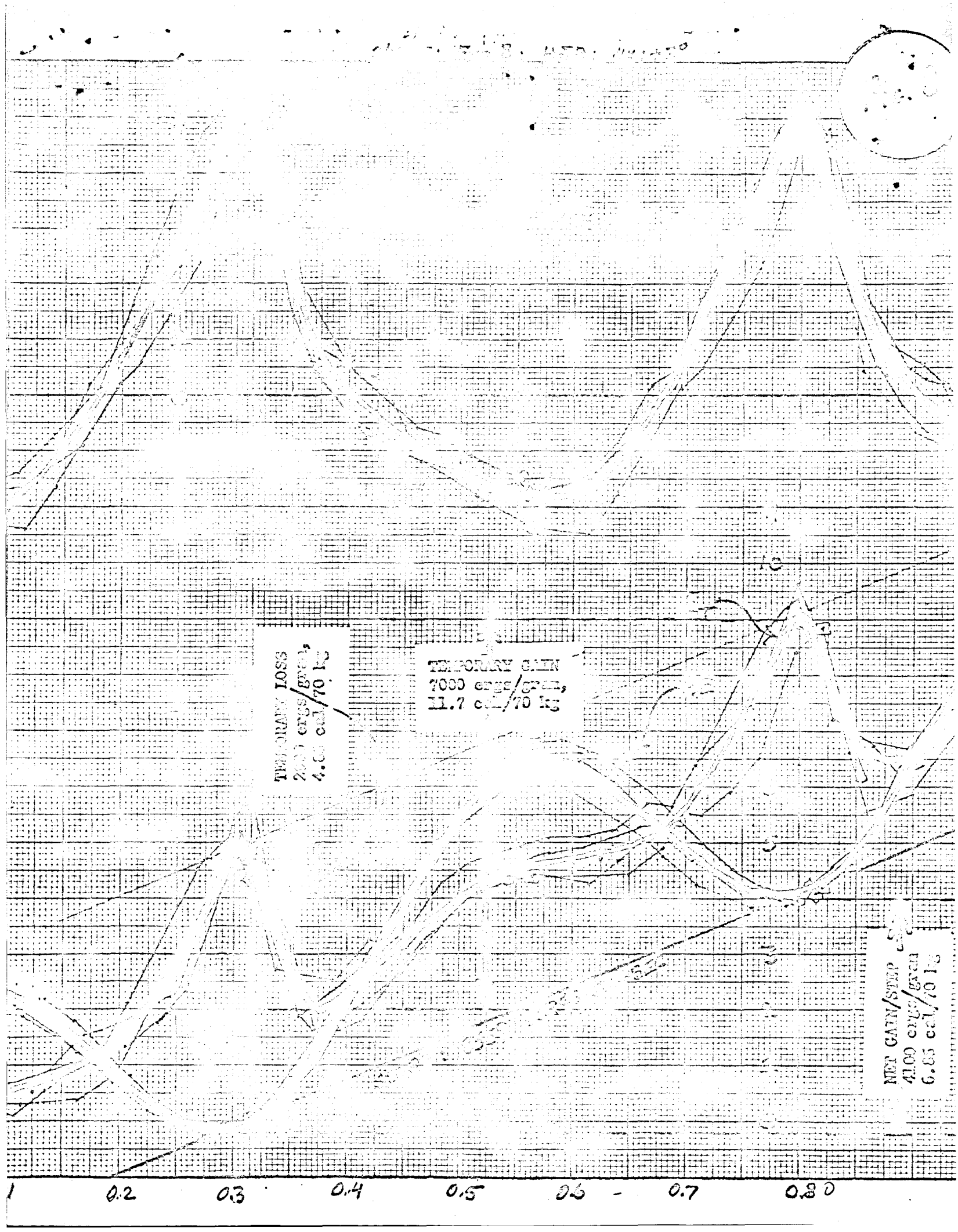


FIG. 7




TEMPORARY GAIN
7000 ergs/gram,
11.7 cal/70 kg
NET GAIN/STEP
1100 ergs/gram
6.85 cal/70 kg
0.2
0.3
0.4
0.5
0.6
0.7
0.80